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HIGH POWER COHERENT X-RAY SOURCE AND SEARCH FOR X-RAY LASER.(U)
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HIGH POWER COHERENT X-RAY SOURCE AND SEARCH FOR X-RAY LASER

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OCTOBER 1976

Research sponsored by the
AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
under Grant AFOSR 72-2373

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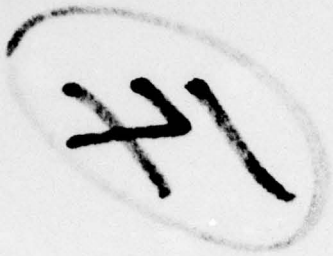

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(11) Oct 76

(12) 26 P.

TABLE OF CONTENTS

(6) HIGH POWER COHERENT X-RAY SOURCE AND SEARCH FOR X-RAY LASER.

(9) FINAL [redacted] REPORT. 1 Jun 72-31 Aug 76,

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JUNE 1, 1972 through AUGUST 31, 1976

(10) Kamalaksha Das Gupta

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I. INTRODUCTION

An intense beam of x-rays as a non-divergent 'hot spot' radiation has been generated when targets with cylindrical bores are bombarded by electrons from a Van de Graaff electron accelerator. An electron beam from the accelerator strikes the target at grazing angles. The details of the experimental results have been previously reported.[1,2] A relationship has been found between the kinetic energy T_n of the electron and the frequency ν_n of the x-radiation generated at the bremsstrahlung limit:

$$T_n = h\nu_n = \frac{2m_0c^2}{n^2-1} \tag{1}$$

where n is any integer greater than 1. The formula (1) has been derived introducing the condition $n\lambda_e = \lambda_\nu$, where λ_e is the de Broglie wavelength of the electron beam and λ_ν is the wavelength of the electromagnetic radiation of frequency ν satisfying the condition $h\nu_n = T_n$, the kinetic energy of the electron. The formula (1) immediately suggests that when a collimated beam of electron of energy T_n strikes the lattice planes d_{hkl} of a single crystal at the required Bragg angle θ_n for the nth order of electron diffraction, the photon of equivalent energy in the bremsstrahlung channel must also suffer a crystal diffraction at the same set of lattice planes at the same Bragg angle θ_n when the photon beam generated in the crystal travel in the same direction as that of the electron beam directed at the same Bragg angle θ_n:

$$n\lambda_e = \lambda_\nu = 2d_{hkl} \sin \theta_n \tag{2}$$

A high power coherent electron and x-radiation source based on the principle of simultaneous diffraction of electrons and x-rays in a crystal at the same Bragg angle as implied in formula (2) has recently been designed. With a proper selection of d and λ, θ could be 90° to obtain the condition of crystal cavity resonator.

In a series of experiments using a single crystal of germanium cut to (111) and (220) planes as targets, pumped simultaneously by x-rays and electrons from G.E. sealed tubes using targets of silver, molybdenum, and copper a new type of coherent Kossel lines has been observed.[3,4] The new lines

appear in addition to the regular Kossel lines that are generated by the Kα and Kβ radiation. Using a high density electron beam in a microfocus x-ray tube Kossel lines have been generated at the copper target. These Kossel lines revealed a non-linear rise in intensity and a narrowing of the fundamental width of copper Kα lines with increase of the electron beam current.[5,6] These results clearly indicate the possibility of fabricating an x-ray laser using a Bragg resonator of single crystal targets generating Kossel lines at the crystal. Based on the preliminary experimental results on the new type of Kossel lines from germanium it seems reasonable to conclude that a greater amplitude for the Auger electron channel should generate more efficiently electron-Kossel cones due to internal diffraction of Auger electrons in the crystal. The concept of the generation of electron-Kossel cones in crystals due to internal Bragg type reflection of electrons and the concept of the anomalous Borrmann type transmission of electrons at Bragg angles are two useful concepts for the development of an x-ray laser. These two concepts have been put forward[4] for the first time in order to explain the new type of coherent Kossel lines from germanium. We have explained the origin of the new type of Kossel lines in germanium to be due to a radiative Auger channel as a virtual electronic Raman process generating Kossel cones in the crystal for the radiative Auger-Raman photons.

The basic approach to understand the mechanism of stimulated emission processes from periodic sources of radiation must originate in Ewald's[7] dynamical theory of x-ray diffraction based on the feedback resonance condition of three dimensional periodic sources at the lattice sites. In generating Kossel-electron cones and Kossel-radiation cones the lattice points are the primary sources of electrons and photons. Ewald's dynamical theory of x-ray diffraction should encompass the dynamics of generation of the Kossel cones. However, a complete analysis should involve the quantum transition probability of (a) characteristic emissions (b) Auger electrons and (c) radiative Auger-Raman processes.

Smith-Purcell[8] effect could be pictured as a coherent process generated in a linear periodic source essentially due to bremsstrahlung at the periodic

ruling of the grating. The dipole waves of Ewald and the dipole waves in Smith-Purcell effect could be treated more or less in a similar way to understand a feedback resonance in periodic sources. Kognelnik and Shank's[9] analysis of the distributed feedback in a tunable laser introducing a gain is a natural extension of Ewald's earlier work on the dynamical theory of x-ray diffraction in it's fundamental aspect. Interaction of relativistic beam of electrons with ruled grating of spacing 'd' generates coherent Smith-Purcell radiation in optical region given by:

$$m\lambda = d\left(\frac{c}{V_0} - \cos\theta\right)$$
$$m = (1,2. \ . \ .) \qquad (3)$$

that follows from a simple Huygen's construction. In our 'hot spot' analysis, the spacing 'd' is of the angstrom order in crystals and the coherent Smith-Purcell type radiation should be in x-ray region. In a three dimensional crystal, these are Kossel lines and we introduce an additional condition:

$$n\lambda_e = \lambda_\nu \qquad (4)$$

which ensures the Bragg reflection condition for photons in a crystal lattice and for electrons at the same lattice at the same Bragg angle. The well known Kossel cones in crystals are due to internal Bragg reflection of characteristic x-rays from the atoms of the crystal. The condition of Kossel cone generation is given by the relation:

$$\cos\alpha = 1/2\ \lambda[d^*_{hkl}] \qquad (5)$$

where d^*_{hkl} is the reciprocal lattice vector, λ is the characteristic wavelength and α is the semivertical angle of the Kossel cones.

In our recent analysis of the 'nondivergent hot spot' from targets with cylindrical bores using Van de Graaff electron accelerator, we have confirmed the existance of 127, 68, 43 and 29 keV radiation. (To be communicated)

I. INTRODUCTION (continued)

REFERENCES:

[1]K. Das Gupta, IEEE J. Quantum Elec., QE-10, 778, (1974).

[2]K. Das Gupta, Phys. Rev. Letters, 33, 1415, (1974).

[3]K. Das Gupta, J. Appl. Phys., 47, 2765, (1976).

[4]K. Das Gupta, International Conference on the Physics of X-Ray Spectra, Gaithersburg, Md., 260, (1976).

[5]K. Das Gupta, Phys. Letters, 46A, 179, (1973).

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[7]P.P. Ewald, Rev. Mod. Phys., 36, 681, (1964).

[8]S.J. Smith and E.M. Purcell, Phys. Rev., 92, 1069, (1953).

[9]H. Kogelnik and C.V. Shank, J. Appl. Phys., 43, 2327, (1972).

II. ACCOMPLISHMENTS REVIEW

1972

Preparation of Copper-Gold Alloy of specific composition.

Copper-gold alloys of the following percentage compositions: atomic percentage of gold: 28.33, 28.35, and 28.30 have been prepared in Professor Pol Duwez's laboratory at the California Institute of Technology. From analysis of these three compositions by x-ray diffraction method done at Texas Tech it has been revealed that the interplanar spacing for 422 planes is very nearly half of the wavelength of copper $K\alpha_1$ peak. The final adjustment of the spacing to obtain internal Bragg resonance would require either some temperature or pressure variation of the sample. By controlling the temperature of the alloy it will be possible to approach the condition of attaining the zero degree Kossel cone. By repeated annealing at 250°C and cold working large grains of single crystals have been obtained with preferred orientation. The preliminary results of fluorescence x-ray emission irradiating the copper-gold alloy with high density electron beam from Febetron 706 reveal concentration of power in forward direction. However, we plan to use similar alloys in which both the constituent elements are of low atomic number.

1973

New Ideas

Das Gupta proposed that the internal Bragg reflection and thereby x-ray resonance of monochromatic radiation could reveal stimulation and high power x-ray laser could thus be obtained.

Accomplishments

a. Successful laboratory demonstration of a new design spherically-bent focusing-type soft x-ray and gamma ray spectrometer, of high resolution and high intensity.

The spectrometer has immediate application to detect the frequency and intensity of soft x-rays from hot plasma, x-ray radiation from Klystron, x-rays from sun and x-ray stars, and investigation of existence of soft

II. ACCOMPLISHMENTS REVIEW (continued)

x-ray associated with thunder storms.

Das Gupta presented his findings in seminars at Weapons Lab, Albuquerque, with Dr. Guenther, Director of Advanced Technology Division, and at Naval Research Laboratory, Washington, D.C. with the laser group headed by Dr. Elton.

b. Observation of a non-divergent electromagnetic radiation, to be referred to as "hot spot", in the energy region 0.3 - 0.6 MeV using a 3 nano-second pulse of high density electron beam from Febetron 706, and a 2 MeV Van de Graaff electron accelerator. This is a coherent bremsstrahlung. Researches are in progress to know the origin of this non-divergent beam. The immediate application will be in radio-therapy.

c. Observation of a non-linear increase in Bragg peak and a narrowing of x-ray lines, with increase of the tube current.

Relevance to Science and Technology

a. The non-divergent hot spot of highly penetrating x-rays in the region of 0.2 - 2 MeV will be extremely useful for materials analysis. The radiography of the structural defects and failures should be revealed with much better contrast as compared to existing methods of x-ray radiography.

b. The highly penetrating non-divergent radiation could be utilized to cause radiation damage to materials and to electronics of some system.

c. The non-divergent beam could be most profitably utilized for radiotherapy.

1974

New Ideas

Das Gupta reported at the VIII International Quantum Electronics Conference a new idea of parametric coupling of electron wavelength with the photon wavelength at the bremsstrahlung limit. The discrete frequencies of the newly observed radiation and it's non-divergent character support the idea of the hypothesis of parametric coupling.

II. ACCOMPLISHMENTS REVIEW (continued)

Accomplishments

So far we have studied the intensity of the newly observed non-divergent radiation with the following materials as targets: lucite, magnesium, aluminum, tin, lead, and tantalum. We have taken targets with cylindrical bore of diameters 2mm, 3mm, 6mm, and 9mm and lengths of 3", 5", 7", and 10". We have also completed the study of the newly observed radiation in a number of conical targets of lead.

We have completed the investigation of the spectroscopic analysis with pulse height multi-channel analyzer. The observed frequencies agree very well with the predicted values from our empirical theory.

We have completed the investigation of the measurement of mass absorption coefficient of the newly observed radiation in lead and it is extremely interesting to point out that the radiation is 2 to 3 times more penetrable in lead. This investigation is being pursued with other materials for individual frequencies in the newly observed beam.

These results have been reported by Das Gupta at the VIII International Quantum Electroncis Conference and in the IEEE Journal of Quantum Electronics.

Relevance to Science and Technology

At the present stage of the development is seems clear that a new electromagnetic process has been discovered. The non-divergent character of the beam can be most profitably utilized in remote operation without power loss and it is extremely hopeful that further investigation would allow us to fabricate a portable x-ray unit with built-in focussing property for useful application in detection of faults in materials, in medical diagnosis, and other usage for remote application for radiation without loss of power. The latter part is now under investigation.

1975

Nature of Work

Stiumlated x-ray emission has been observed from single crystals of germanium and copper. Discrete frequencies in bremsstrahlung have been

II. ACCOMPLISHMENTS REVIEW (continued)

reported.[1] Anomalous small angle x-ray diffraction has been observed. Based on these three new observations the research team at the Radiation Laboratory at Texas Tech University is engaged to obtain the amplification that would justify the announcement of the discovery of the x-ray laser.

New Ideas

In explaining the stimulated radiation of germanium crystal, Das Gupta has introduced a new idea of stimulated emission of Auger electrons in germanium crystal. The momentum of the Auger electron from germanium happens to satisfy the hypothesis $n\lambda_e = \lambda\nu$ or $np_\nu = p_e$ as reported by Das Gupta.[1]

Accomplishments

a. Using a Ge(Li) detector the peaks at 127, 68, 43, and 29 keV have been confirmed. (to be reported)

b. Small angle diffraction with newly observed hot spot radiation from Cu, Sn, Be, and C confirm the presence of 29.2 keV, 21 keV, and 16 keV radiation as predicted from Das Gupta's formula.[1]

c. Spectroscopy of the continuous radiation from G.E. x-ray tube reveals discrete humps of 29 keV, 21 keV, and 16 keV.

d. A magnetic spectrometer is nearly in completion to study the discrete energies of electrons in hot spot experiments.

e. A single crystal of aluminum target cut to (111) plane is being used to obtain stronger hot spot due to internal Bragg reflection of discrete frequencies at 29 keV.

Relevance to Science and Technology

A future extension of this work will lead us to more powerful coherent x-ray source of many useful applications in therapy, diagnosis, and other practical radiography. Highly coherent x-ray lines that we have obtained from single crystal of germanium can be used to make an x-ray hologram to visualize the inner structures and faults of materials of submicroscopic and molecular dimension.

II. ACCOMPLISHMENTS REVIEW (continued)

[1]K. Das Gupta, "Nondivergent Radiation of Discrete Frequencies in Continuous X-ray Spectrum"; Physical Review Letters; December 1974.

The published results have been reported at the University of London, University of Paris, Rostov State University, USSR, California Institute of Technology, University of Miami, and University of Texas at Austin.

1976

Two regular Kossel lines have been observed in germanium crystal with wavelengths of 1.134 and 1.246 Å due to germanium $K\beta_1$ and $K\alpha_{1,2}$ radiation. Two additional Kossel-type lines on the low energy side of germanium $K\alpha_{1,2}$ with wavelengths of 1.391 and 1.544 Å have also been observed. The energy of these newly observed lines correspond to the kinetic energies of the Auger electrons of germanium involving K and L levels. The newly observed radiation is characterized by the following properties: (i) a non-linear rise in intensity with pumping, (ii) anomalous mass absorption coefficient in aluminum and silicon so far studied, (iii) preliminary results reveal an unusually narrow fundamental width of the newly observed lines.

III. PUBLICATIONS

1. The following is a list of publications from 1972 to 1976 supported by AFOSR Grant 72-2373 funds and equipment.

K. Das Gupta, P.F. Gott, Herbert Welch, John F. Priest, Sunny Cheng, and Edmond Chu
"Some New Methods of Precision X-Ray Spectrometry"
Advances in X-Ray Analysis, 16, 251, (1972).

K. Das Gupta
"Evidence of Stimulation in X-Ray Emission"
Colloquium Spectroscopicum Internationale XVII, ACTA II, (1973).

K. Das Gupta
"Non-Linear Increase in Bragg Peak and Narrowing of X-Ray lines"
Physics Letters, 46A, 179, (1973).

K. Das Gupta
"Observation of Coherent Characteristic Frequencies in Bremsstrahlung"
IEEE Journal of Quantum Electronics, QE-10, 778, (1974).

K. Das Gupta and S.M. Shah
"Observation of Fine Structures in $K\alpha_1$ Lines of 3d Transition Elements Using a Three Crystal Spectrometer
Journal of the Physical Society of Japan, 37, 1069, (1974).

K. Das Gupta and S.M. Shah
"A High Resolution Three Crystal Spectrometer for the Use in X-Ray Emission Spectroscopy"
Japanese Journal of Applied Physics, 13, 2042, (1974).

K. Das Gupta
"Non-Divergent Radiation of Discrete Frequencies in Continuous X-Ray Spectrum"
Physical Review Letters, 33, 1415, (1974).

K. Das Gupta
"Diffraction of Discrete X-Ray Frequencies from Germanium Atoms in Crystals"
Journal of Applied Physics, 41, 2765, (1976).

K. Das Gupta
"A New Type of Kossel-Borrmann Radiation from Germanium Crystal"
International Conference on the Physics of X-Ray Spectra, Gaithersburg, Md., 260, (1976).

III. PUBLICATIONS

2. Abstracts

SOME NEW METHODS OF PRECISION X-RAY SPECTROMETRY

K. Das Gupta, Herbert Welch, P.F. Gott, John F. Priest, Sunny Cheng, and Edmond Chu

Advances in X-Ray Analysis, 16, 251, (1972).

Three novel methods of x-ray spectrometry have been developed in recent years at Texas Tech University. These are:

1. Three crystal spectrometer
2. Two curved crystal spectrometer
3. Spherically bent crystal spectrometer.

In this paper the new design features, and experimental results will be discussed to indicate the usefulness of the new instruments. The three crystal spectrometer is a modified two crystal instrument. A third crystal is used to analyze the output of the two crystal spectrometer. The first two crystals are operated as a standard two crystal spectrometer. The third crystal is swept through the spectrum transmitted by the first two crystals for each setting of the first two crystals. The peak intensity of the third crystal sweep corresponds to the energy setting of the two crystal spectrometer, and is the intensity used to plot the spectral lines. The two curved crystal spectrometer utilizes two transmission spectrographs with radii having a 2:1 ratio in series, the crystal with the smaller radius being set so that its focal point falls on the Rowland circle of the larger radius crystal. This instrument has a very low background intensity and is suitable for precision scattering and diffraction work. The spherically bent crystal spectrometer makes use of high light gathering power and high orders of reflection to allow high resolution studies of weak spectral lines. It also has the advantage of ease of alignment and operation.

EVIDENCE OF STIMULATION IN X-RAY EMISSION

K. Das Gupta

Colloquium Spectroscopicum Internationale XVII, ACTA II, (1973).

Using a high current density at the polycrystalline copper of a micro-focus x-ray tube, I have observed a non-linear increase of the peak intensity of copper $K\alpha_1$ and $K\alpha_2$ radiation. The percentage increase of intensity above the normal linear increment is 50 percent for copper $K\alpha_1$ and about 35 percent for copper $K\alpha_2$. The full width at half maximum intensity narrows more than 30 percent for copper $K\alpha_1$ when the tube current is increased from 0.2mA to 1mA. A spherically bent crystal spectrometer designed by the author has been most successfully used to study these non-linear effects.

III. PUBLICATIONS

2. Abstracts (continued)

NON-LINEAR INCREASE IN BRAGG PEAK AND NARROWING OF X-RAY LINES

K. Das Gupta

Physics Letters, 46A, 179, (1973).

Using high current densities at the copper target, the intensity of the copper Kα peak is found to increase by more than 50 percent above the normal linear increment. In addition, the fundamental width of this line decreases with the increase of the tube current.

OBSERVATION OF COHERENT CHARACTERISTIC FREQUENCIES IN BREMSSTRAHLUNG

K. Das Gupta

IEEE Journal of Quantum Electronic, QE-10, 778, (1974).

A nearly non-divergent coherent beam of electromagnetic radiation of characteristic discrete frequencies is produced propagating in a direction slightly inclined to the target face, when electrons in the energy range of 200-450 keV strike the smooth surface of solids: conductors, semiconductors, or insulators.

OBSERVATION OF FINE STRUCTURES IN THE Kα LINES OF 3d TRANSITION ELEMENTS USING A THREE CRYSTAL SPECTROMETER

K. Das Gupta and S.M. Shah

Journal of the Physical Society of Japan, 37, 1069, (1974).

Using a newly developed high resolution three crystal spectrometer fine structures in the Kα lines of chromium and cobalt, in their pure metallic form, have been observed. These investigations qualitatively prove that the asymmetry in the Kα lines of the 3d group transition elements is the result of the multiplet structure of $L_1(2p_{1/2})$ and $L_3(2p_{3/2})$ levels due to their splittings in 2 and 4 sublevels respectively as proposed by Izraileva and Nefedov in their theoretical calculations. The observed fine structures are, therefore, the result of the transitions from these sublevels to the K(1s) level.

III. PUBLICATIONS

2. Abstracts (continued)

A HIGH RESOLUTION THREE CRYSTAL SPECTROMETER FOR THE USE IN X-RAY EMISSION SPECTROSCOPY

K. Das Gupta and S.M. Shah

Japanese Journal of Applied Physics, 13, 2042, (1974).

A new technique of using a three crystal arrangement in x-ray emission spectroscopy (XS) has been developed. Fine structures in the Kα lines of the iron group transition elements have been observed, for the first time, using this technique. Similarly, the line widths at half maximum of the Kα emission lines observed using this method are narrower than those observed with the two crystal spectrometers. The design of a three crystal spectrometer suitable for the use in XS is also presented.

NONDIVERGENT RADIATION OF DISCRETE FREQUENCIES IN CONTINUOUS X-RAY SPECTRUM

K. Das Gupta

Physical Review Letters, 33, 1415, (1974).

I have observed a strong nondivergent beam of radiation from targets with cylindrical bores, emitted in a direction parallel to the target face, when electrons strike the target at grazing angles. The spectroscopic analysis has so far revealed six discrete bands in the range 350-20 keV, which agree well with my predicted values. The theory of bremsstrahlung apparently does not account for the high intensity in the forward direction or for the discrete frequencies of the radiation.

DIFFRACTION OF DISCRETE X-RAY FREQUENCIES FROM GERMANIUM ATOMS IN CRYSTALS

K. Das Gupta

Journal of Applied Physics, 41, 2765, (1976).

Two distinct Kossel lines and two additional Kossel-type lines are generated by the [220] reflections of germanium single crystals irradiated by Cu and Mo radiation. The wavelengths of these lines as calculated from the observed Bragg angles are 1.134, 1.246, 1.391, and 1.544 Å corresponding to energies of 10.931, 9.949, 8.912, and 8.029 keV, respectively. The lines appearing at 1.134 and 1.246 Å are due to $K\beta_1$ and $K\alpha_{1,2}$ of germanium. The Kossel-

III. PUBLICATIONS

2. Abstracts (continued)

DIFFRACTION OF DISCRETE X-RAY FREQUENCIES FROM GERMANIUM ATOMS IN CRYSTALS

(continued)

type lines of wavelengths 1.391 and 1.544 Å are of lower-energy value than germanium Kα, and therefore cannot be classified as regular Kossel lines.

A NEW TYPE OF KOSSEL-BORRMANN RADIATION FROM GERMANIUM CRYSTAL

K. Das Gupta

International Conference on the Physics of X-Ray Spectra, Gaithersburg, Md., 260, (1976).

Two regular Kossel lines have been observed in germanium crystal with wavelengths of 1.134 and 1.246 Å due to germanium $K\beta_1$ and $K\alpha_{1,2}$ radiation. Two additional Kossel-type lines on the low energy side of germanium $K\alpha_{1,2}$ with wavelenghts 1.391 and 1.544 Å have also been observed. The energy of these newly observed lines correspond to the kinetic energies of the Auger electrons of germanium involving K and L levels. The newly observed radiation is characterized by the following properties: (i) a non-linear rise in intensity with pumping, (ii) anomalous mass absorption coefficient in aluminum and silicon so far studied, (iii) preliminary results reveal an unusually narrow fundamental width of the newly observed lines.

III. PUBLICATIONS

3. Papers Planned for Publication in the Near Future

1. "Coherent Interactions of Electrons and Photons in Periodic Field"
2. "Coherent Kossel-Type Lines from Germanium Crystal"
3. "Discrete Frequencies in Bremsstrahlung Between 8 keV to 45 keV"
4. "Spectroscopy of Non-Divergent Radiation from Single Crystal of Aluminum"
5. "Coherent Kossel-Type Radiation from Sapphire Crystal"

IV. ORAL PRESENTATIONS

The following is a listing of invited papers or lectures presented during the period supported by AFOSR Grant 72-2373.

1972

Bose Endowment Lecture: Bose Institute, Calcutta, India, May 1972; "X-Ray Laser".

Special Lecture: National Aeronautical Laboratory, Bangalore, India, May 1972; "Electron States of Solids".

Ripon Professorship Lecture: India Association for the Cultivation of Science, Calcutta, India, May 1972; "X-Ray Laser".

Special Lecture: Indian Institute of Technology, Kharagpur, India, May 1972; "Band Structure of Solids".

Annual Denver Conference on Application of X-Ray Analysis: Denver, Colorado, August 1972; "Some New Methods of Precision X-Ray Spectrometry" (co-authored).

1973

Lecture: Advanced Technical Division, Laser Laboratory, Kirtland Air Force Base, Albuquerque, New Mexico, February 1973; "Non-Divergent Radiation from Using Van de Graaff Accelerator".

Lecture: Naval Research Laboratory, Washington, D.C., May 1973; "Evidence of Stimulated Emission of X-Rays".

Conference: American Crystallographic Association, University of Connecticut, Storr, Connecticut, June 1973; "Non-Linear Increase in Bragg Peak and Narrowing of X-Ray Lines".

Annual Denver Conference on Application of X-Ray Analysis: Denver, Colorado, August 1973; "A Super Resolution in X-Ray Spectroscopy" (co-authored paper).

Seminar: Laboratoire De Chimie Physique, Université de Paris, Paris, France, September 1973; "Stimulated X-Ray Emission".

Colloquium Spectroscopicum Internationale, Florence, Italy, September 1973; "Evidence of Stimulation in X-Ray Emission".

Seminar: Bose, Institute, Calcutta, India, December 1973; "Development of X-Ray Laser".

Seminar: Indian Association for the Cultivation of Science, Calcutta, India, December 1973; "Electronic States of Alloys".

Seminar: Department of Physics, Calcutta University, Calcutta, India, December 1973; "Stimulated Compton Scattering".

Seminar: Indian Institute of Technology, Kharagpur, India, December 1973; "Electron States of Solids".

IV. ORAL PRESENTATIONS (continued)

1974

Seminar: Indian Institute of Science, Bangalore, India, January 1974; "Evidence of Stimulated Emission of X-Rays".

Seminar: Raman Research Institute, Bangalore, India, January 1974; "Production and Properties of Newly Observed Non-Divergent X-Ray Beam in MeV Region".

Seminar: Department of Physics, University of Delhi, Delhi, India, January 1974; "Stimulated Compton Scattering".

Colloquium at the University of Rochester, Laboratory of Laser Energetics and Institute of Laser Optics, Rochester, New York, April 1974; "Coherent Interactions of Electrons and Photons in Crystals".

VIII International Quantum Electronics Conference, San Francisco, Califfornia, June 1974; "Observation of Coherent Characteristic Frequencies in Bremsstrahlung".

Colloquium at Los Alamos Scientific Laboratory, Los Alamos, New Mexico of the University of California, August 1974; "Some Evidence of Stimulated Emission from Germanium Crystals".

Seminar: Department of Electrical Engineering, California Institute of Technology, Pasadena, California, November 1974; "Kossel Borrmann Radiation from Germanium Crystal".

1975

Orbis Scientiae II, Center for Theoretical Studies, University of Miami, Coral Gables, Florida, January 1975; "Observation of Enhanced Intensity of Kossel-Borrmann Lines in Germanium Crystal".

Special Lecture: Wayland Baptist College, Plainview, Texas, February 1975; "X-Ray Laser and Production Mechanism".

Special Lecture at Birkbeck College, University of London, London, England, September 1975; "Coherent Production of X-Rays".

Opening Lecture Second Day, XI All-Union Conference on X-Ray Spectroscopy, Rostov State University, Rostov-on-the-Don, USSR, September 1975; "Kossel-Borrmann Lines in Germanium Crystal".

Theoretical Seminar: University of Texas at Austin, Austin, Texas, October 1975; "Recent Findings in Radiation".

Symposium on X-Ray Spectroscopy and Its Application, University of Allahabad, Allahabad, India, December 1975; Presiding Chairman, First Session and Lecturer; "Stimulated Kossel-Borrmann Emission in Germanium Crystal".

Lecture: Indian Association for the Cultivation of Science, Calcutta, India, December 1975; "X-Rays from Germanium Crystal Cavity".

IV. ORAL PRESENTATIONS (continued)

1975

Special Lecture: University of Delhi, New Delhi, India, December 1975; "X-Ray Laser from Germanium Crystal Cavity".

1976

Special Conference: Los Alamos Scientific Laboratory, Laser Division, Los Alamos, New Mexico of the Univeristy of California, April 1976; "A New Type of Kossel-Lines from Germanium Crystal".

Seminar: Department of Electrical Engineering, Texas A & M University, College Station, Texas, June 1976; "Non-Divergent X-Rays with Van de Graaff Accelerator".

International Conference on the Physics of X-Ray Spectra, National Bureau of Standards, Gaithersburg, Maryland, August-September 1976; "Diffraction of Discrete X-Ray Frequencies from Germanium Atoms in Crystals".

V. CITATIONS

The following is a list of known citations of K. Das Gupta's research work supported by AFOSR Grant 72-2373.

I. Freumd
NONLINEAR X-RAY DIFFRACTION. DETERMINATION OF VALENCE ELECTRON CHARGE DISTRIBUTIONS
Chemical Physics Letters, 12, 583, (1972).

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Czech. Journal of Physics B, 22, (1972).

P. Eisenberger, N.G. Alexandropoulos, and P.M. Platzman
X-RAY BRILLOUIN SCATTERING
Physical Reveiw Letters, 28, (1972).

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Nov. 29, (1973).

D.J. Nagel
APPROACHES TO HIGH PHOTON ENERGY LASERS
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California Institute of Technology, February, 311, 314, (1976).

V. CITATIONS (continued)

Ronald W. Waynant and Raymond C. Elton
REVIEW OF SHORT WAVELENGTH LASER RESEARCH
Proceedings of the IEEE, 64, 1059, (1976).

VI. DISSERTATIONS AND THESIS

1. The following is a list of dissertations and theses supported in part by AFOSR Grant 72-2373 funds and equipment.

Bruce H. Armstrong
M.S. 1972
"Precision X-Ray Spectrometry at Low Temperatures"

Hua May Lin Chen
M.S. 1972
"X-Ray Study of the Transition of Amorphous Ni_{63}-Pd_{17}-Pd_{20}"

Shih King Cheng
M.S. 1972
"Precision X-Ray Spectroscopy in High Orders of Reflection"

Franklin Potter
Ph.D. 1973
"Soft X-Ray Spectra of Aluminum Nickel Alloys"

Amy F. Lin
M.S. 1974
"Anomalous X-Ray Diffraction at Small Angles"

Taiann Hwa
M.S. 1975
"Study of Borrmann Effect in Silicon Crystals"

In Progress:

Shih King Cheng
Ph. D.
"Electron States of Some Superconducting Elements and Alloys"

Amy F. Lin
Ph. D. (leave of absence September, 1976)
"Soft X-Ray Spectroscopy of Oxygen in Compounds"

Robert Mays, Jr.
Ph. D.
"Compton Scattering from Single Crystals"

VIII. PERSONNEL

1. The following is a list of all personnel supported in whole or part with AFOSR Grant 72-2373 funds and equipment or by matching funds from Texas Tech University.

RESEARCH ASSOCIATE	
Preston F. Gott	July-August 1972 July-August 1973 July-August 1975
POST-DOCTORAL RESERACH FELLOW	
Peter J. Seibt	September 1974-August 1976
SENIOR TECHNICIAN	
Bob L. Burch	June 1972-August 1976
TECHNICIAN	
Bill Goss	September-December 1973
Robert Turner	September 1975-January 1976
James Albone	February-August 1976
LAB ATTENDANT	
Beverly Starks	June 1972-December 1973 May-August 1974
Barbara Bollen	June 1973-April 1974
Aleeta Sue Cooper	September 1974-August 1976
GRADUATE RESEARCH ASSISTANT	
Frank Potter	August 1972
UNDERGRADUATE RESEARCH ASSISTANT	
Edmund Chu	September 1972-April 1973
Bill Morrison	February 1973-April 1975
Robert Turner	May 1974-August 1975
James White	February-May 1976
STUDENT ASSISTANT	
Karen Klager	May-August 1974
Suzanne Kennedy	November 1974-April 1975

VII. PERSONNEL

2. Listed below are those persons working in related projects within the radiation research lab during the period of June 1, 1972 through August 31, 1976 but not supported by AFOSR funds.

POST-DOCTORAL RESEARCH FELLOW	
Q.S. Kapoor	May 1972-June 1973
Peter J. Seibt	April 1973-August 1974
Sheldon S. Wald	June-August 1976
GRADUATE RESEARCH ASSISTANT	
Shih King Cheng	June-August 1972 August 1975-August 1976
Amy Lin	June 1972-August 1976
Jerry Hwa	September 1973-May 1975
Hau May Chen	June-August 1972
John Priest	June 1972-August 1973
Charles Yung-Kang Chen	September 1973-August 1974
Robert Mays, Jr.	August 1975-August 1976
UNDERGRADUATE RESEARCH ASSISTANT	
Joe Dannemiller	June 1972-August 1976
Bill Morrison	June 1972-January 1973
Robert Turner	June 1972-April 1974
Edmund Chu	May-August 1973
Bill Goss	June-August 1973
James Lard	September-December 1975
James Albone	November 1975-January 1976
Bruce Carter	January-May 1976
Kim Shinn	February-August 1976
James White	June-August 1976
STUDENT ASSISTANT	
Olarn Boontheekul	September 1975-May 1976
Terry Creech	September-December 1975
Nancy Mason	March-May 1976
Ann Welch	July-August 1976

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Stimulated Kossel, Non-divergent 'hot spot', Soft x-ray laser, Laser from crystal cavity, Coherent electron from crystal cavity, Stimulated radiative Auger Raman process

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Non-divergent 'hot spot' from single crystals bombarded with electron beam from Febetron and Van de Graaff and sealed-off x-ray tube reveals discrete frequencies in bremsstrahlung. Stimulated Kossel line and radiative Auger Raman process have been observed in germanium crystal. Conical target x-ray tube bombarded by electrons at grazing angle give high contrast radiograph of materials and instruments. The observed coherent radiation has been profitably used for surface studies and could be used for development of x-ray holography.

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